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(54) **REAL-TIME MONITORING SYSTEMS AND METHODS IN A HEALTHCARE ENVIRONMENT**

(58) **Field of Classification Search**
CPC combination set(s) only.
See application file for complete search history.

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(65) **Prior Publication Data**

(57) **ABSTRACT**

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An apparatus for real time monitoring of a patient is provided and includes a memory element for storing data, a processor that executes instructions associated with the data, an interface that receives sensor data from a sensor that takes measurements from the patient and sends the sensor data according to the sensor's measurement latency, a latency calculator that frequently calculates a latency threshold that varies according to at least a health status of the patient, a timer that continuously monitors the sensor's measurement latency, a comparator that frequently compares the sensor's measurement latency with the calculated latency threshold, and a feedback module that automatically changes the sensor's measurement latency to match with the calculated latency threshold.

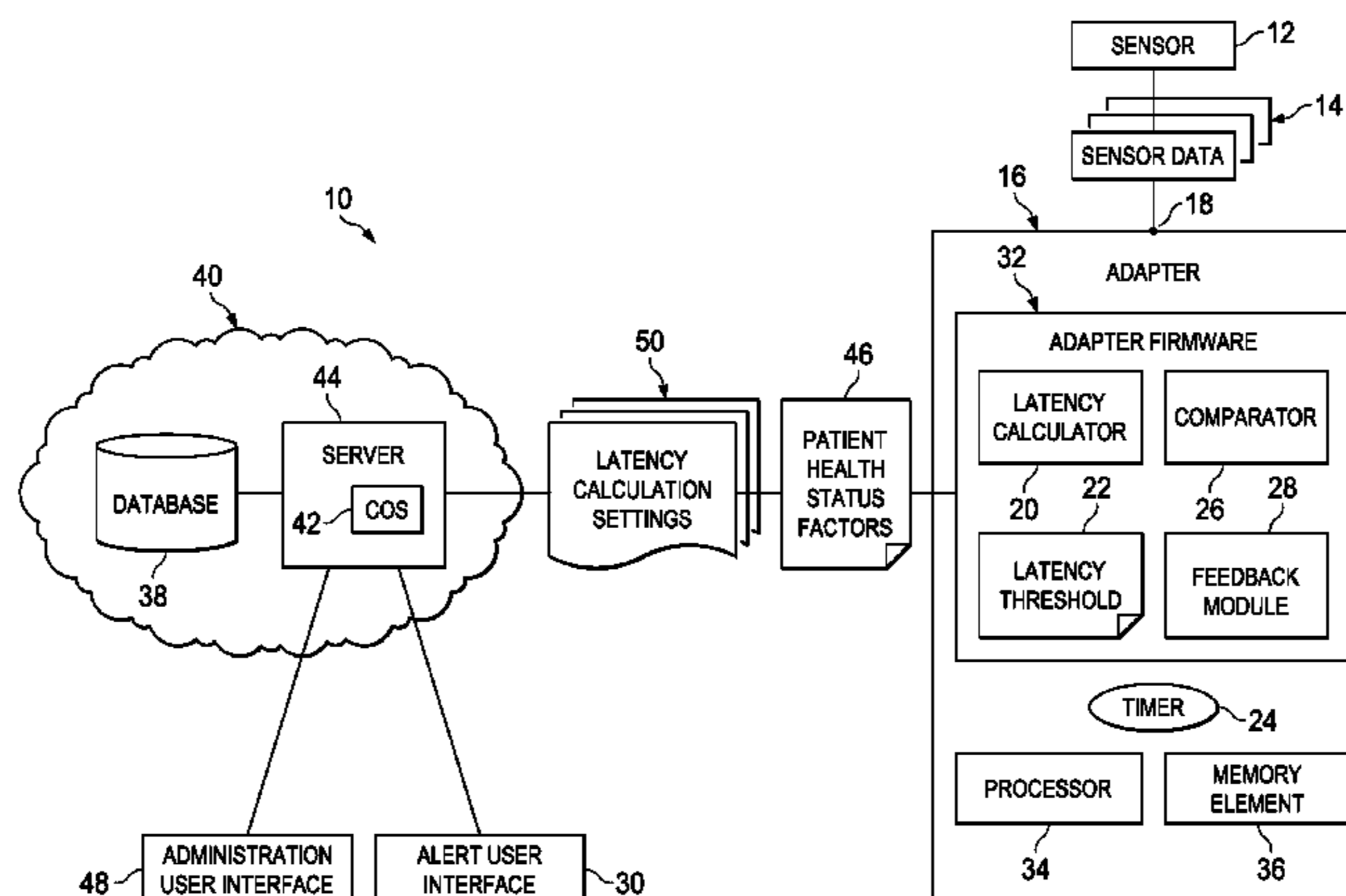
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20 Claims, 6 Drawing Sheets

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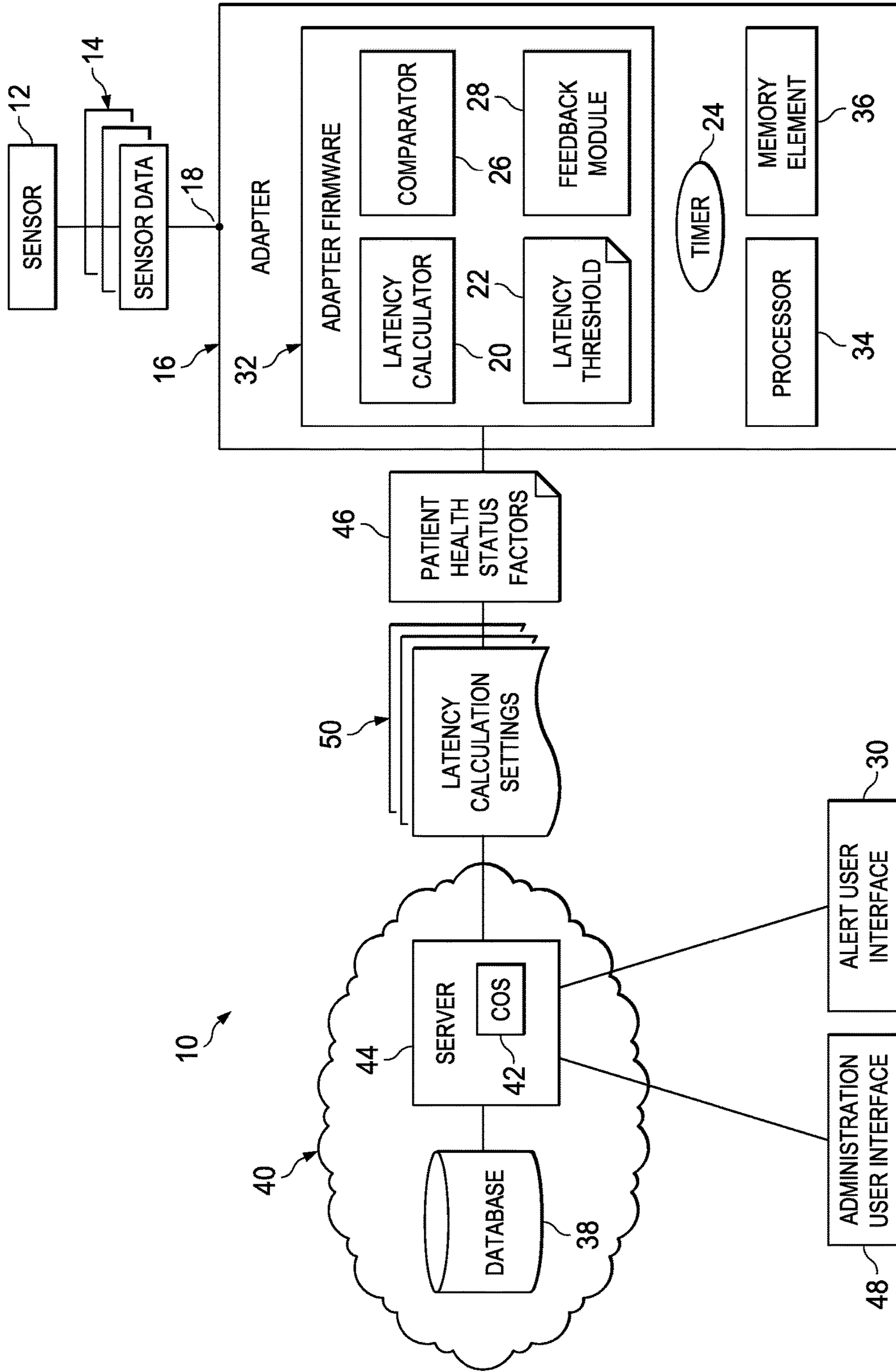
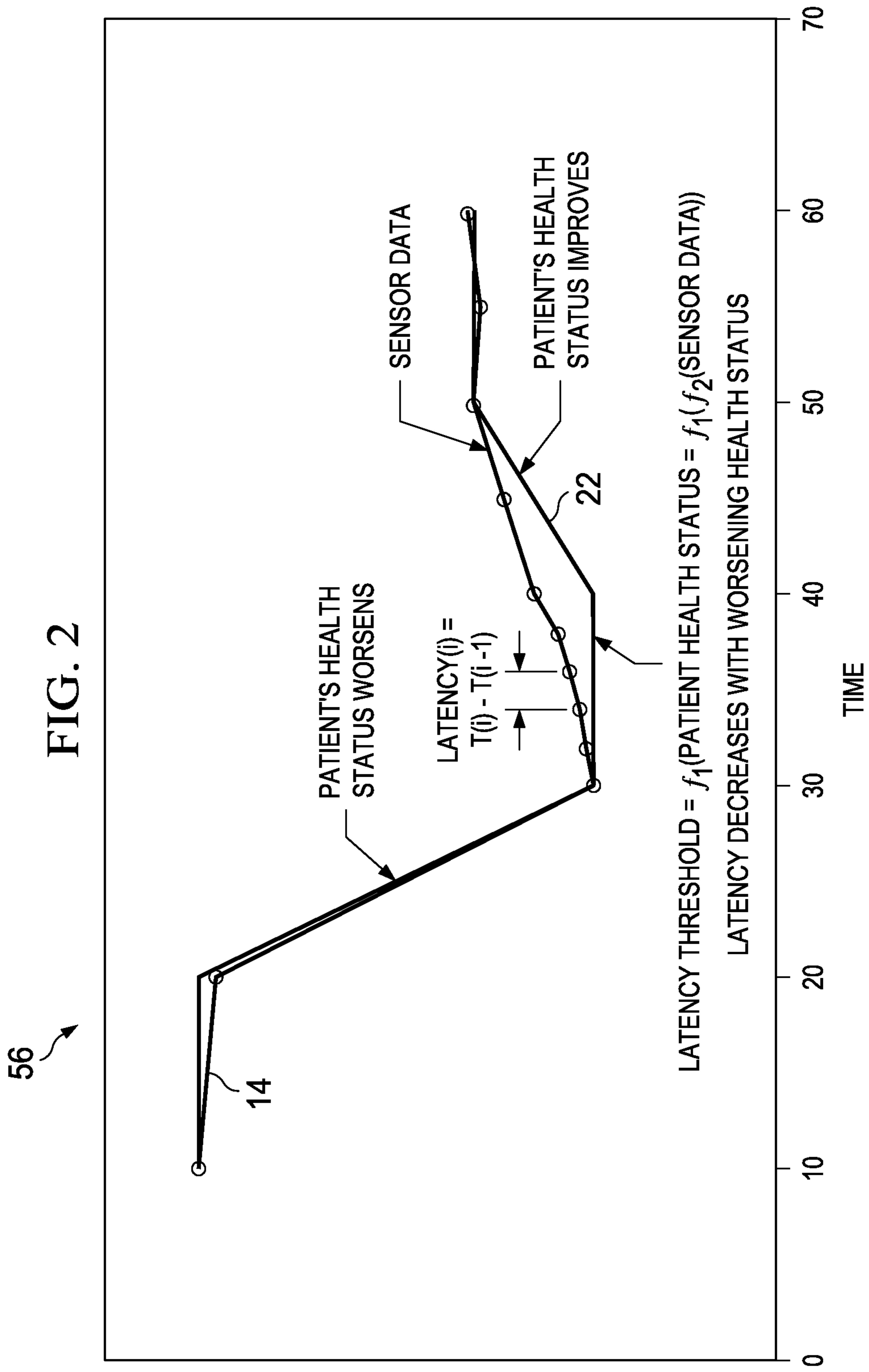


FIG. 1



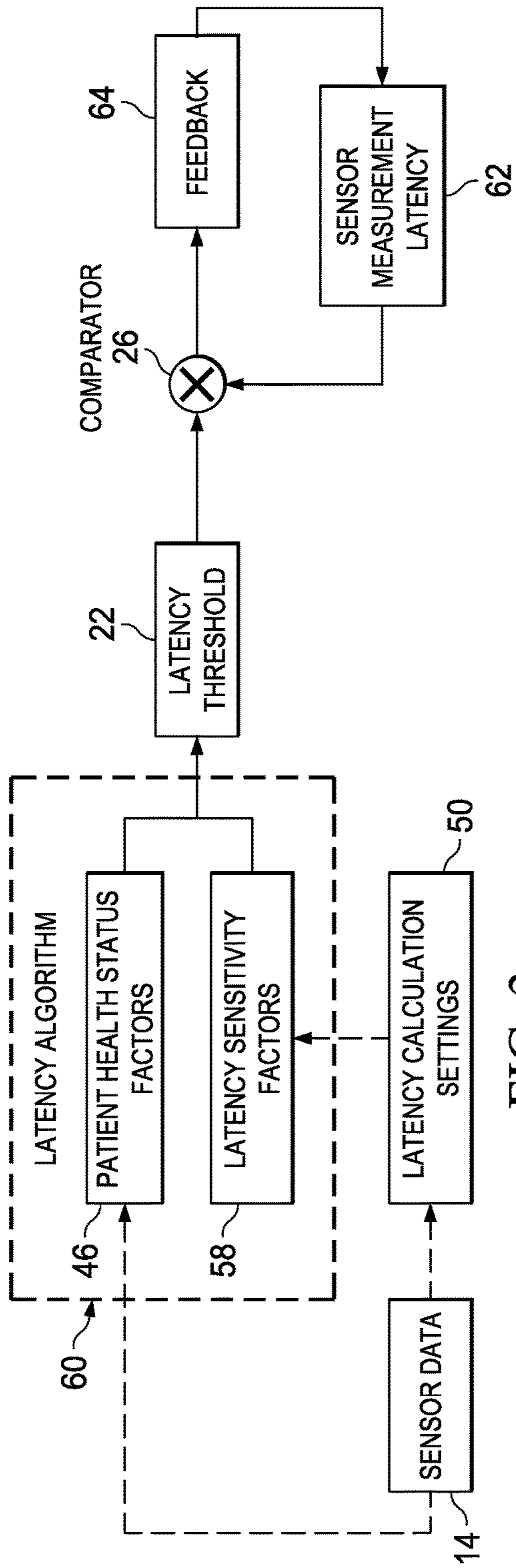


FIG. 3

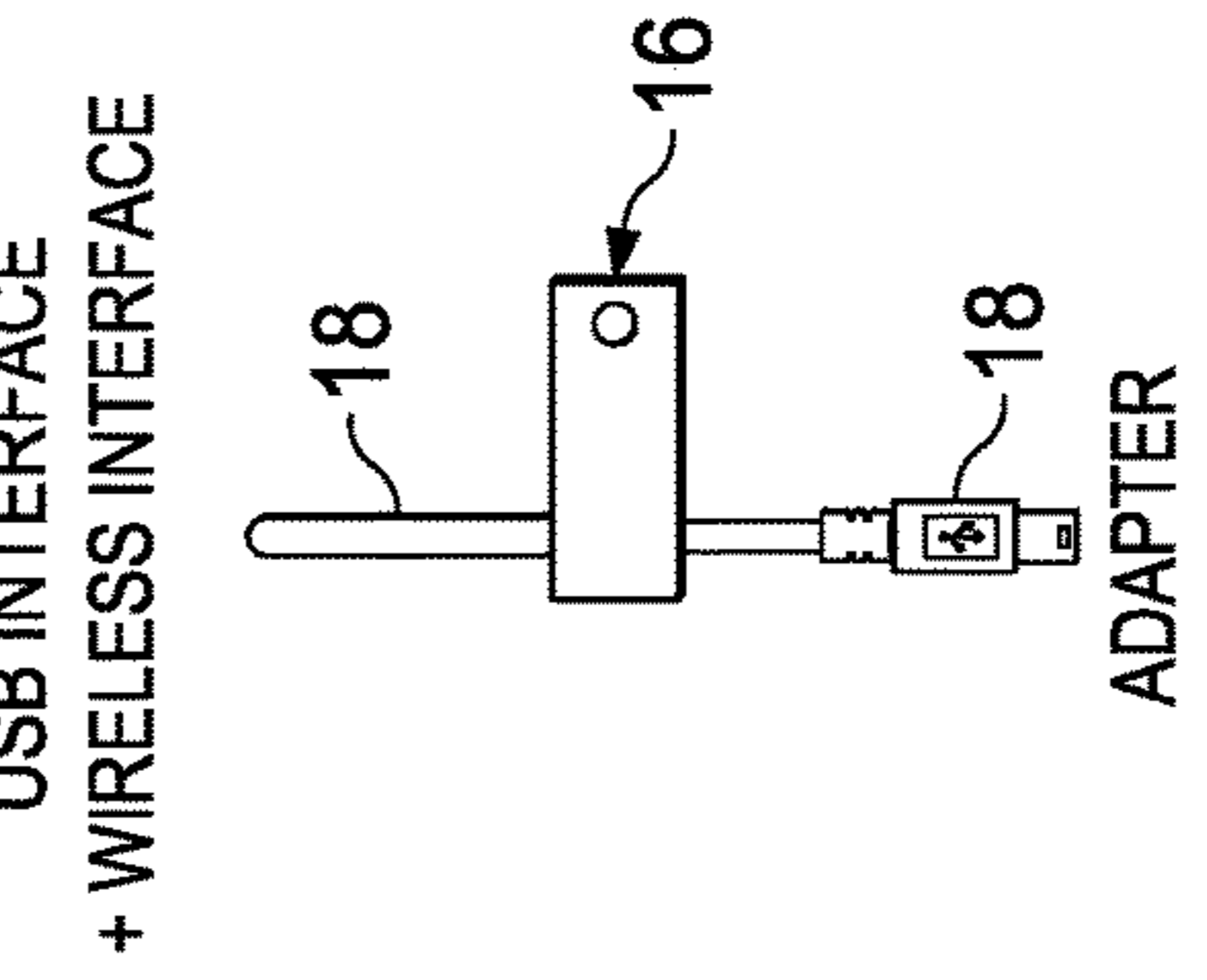


FIG. 4A

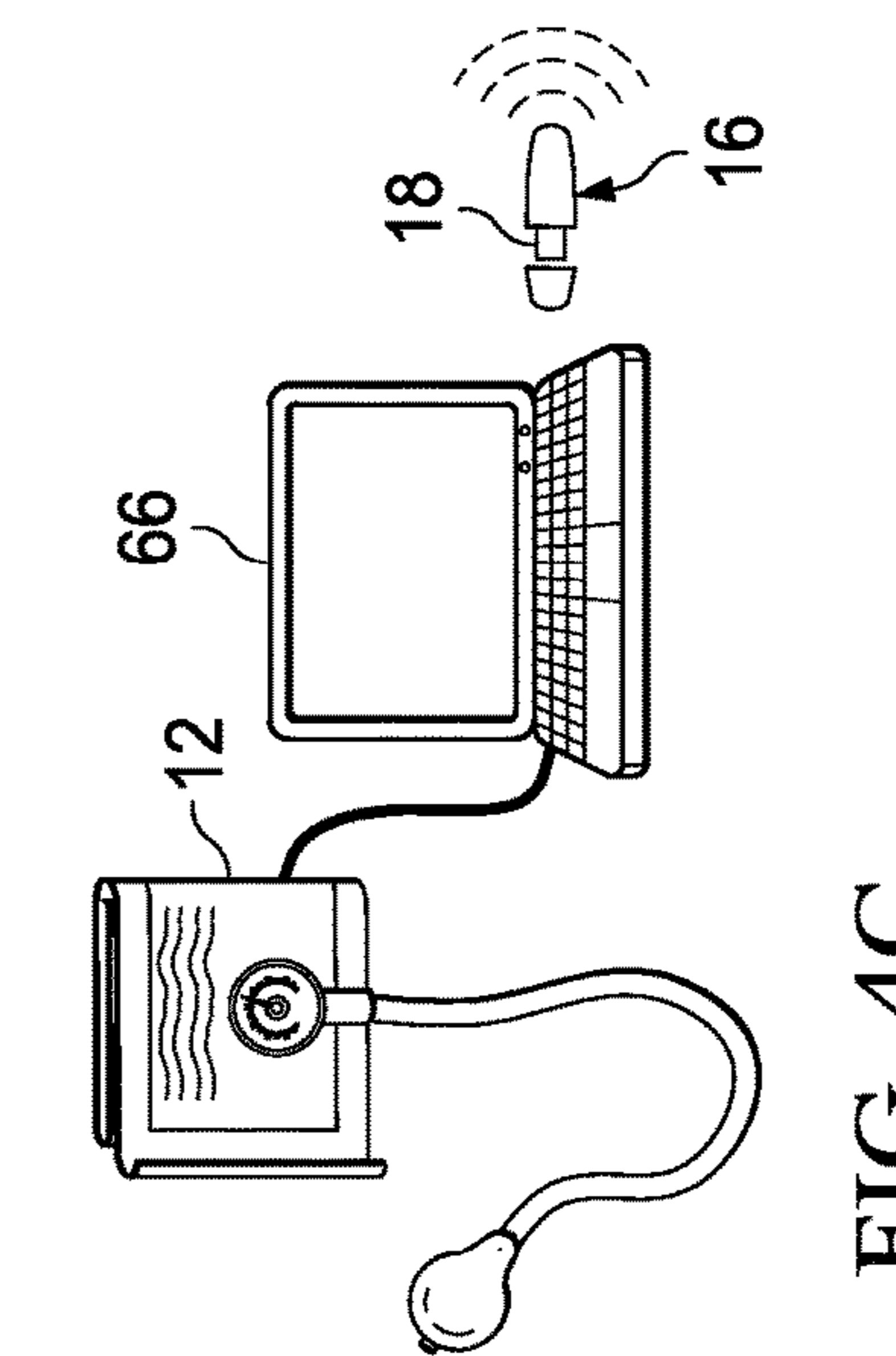


FIG. 4B

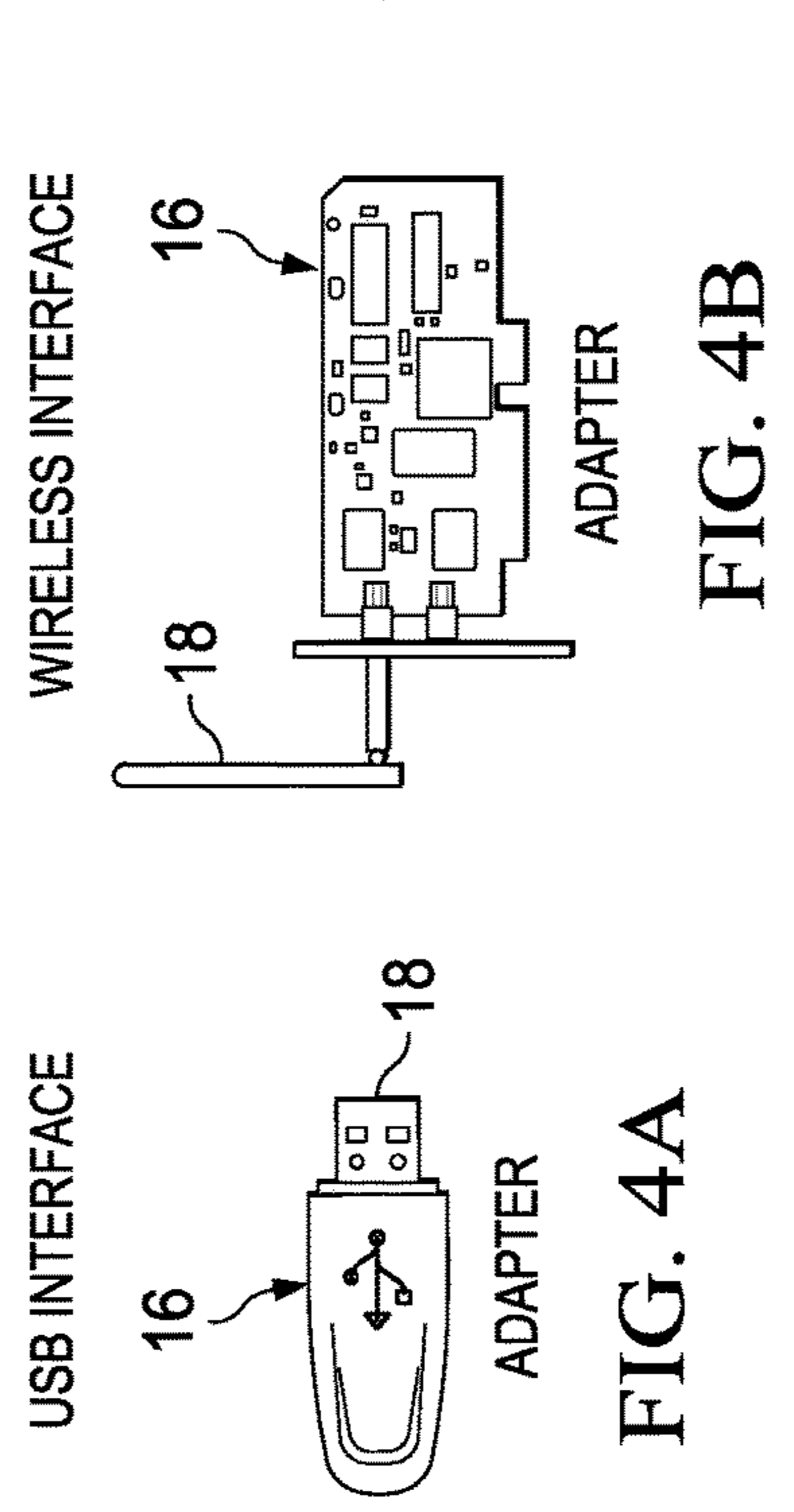


FIG. 4C



FIG. 4D

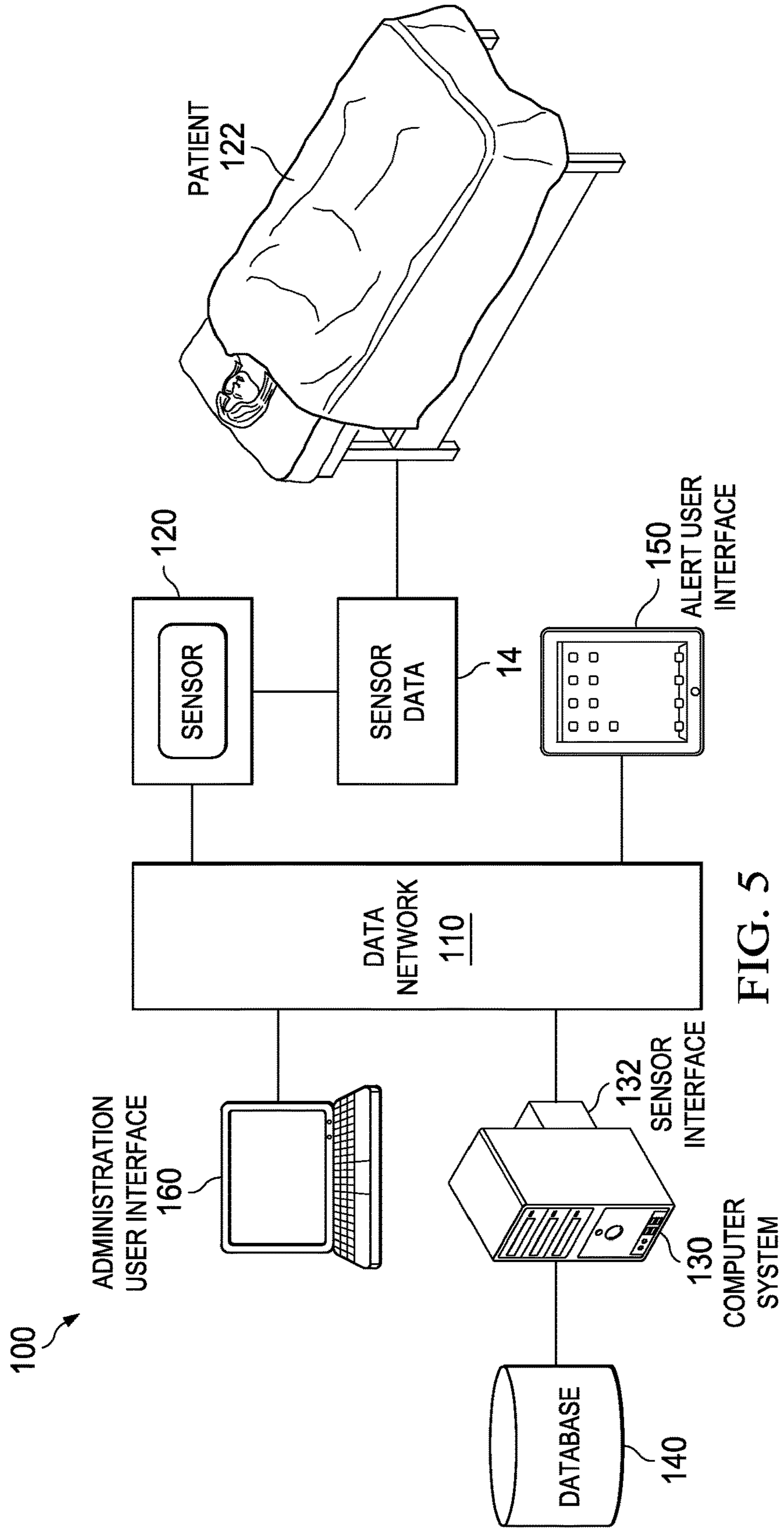


FIG. 5

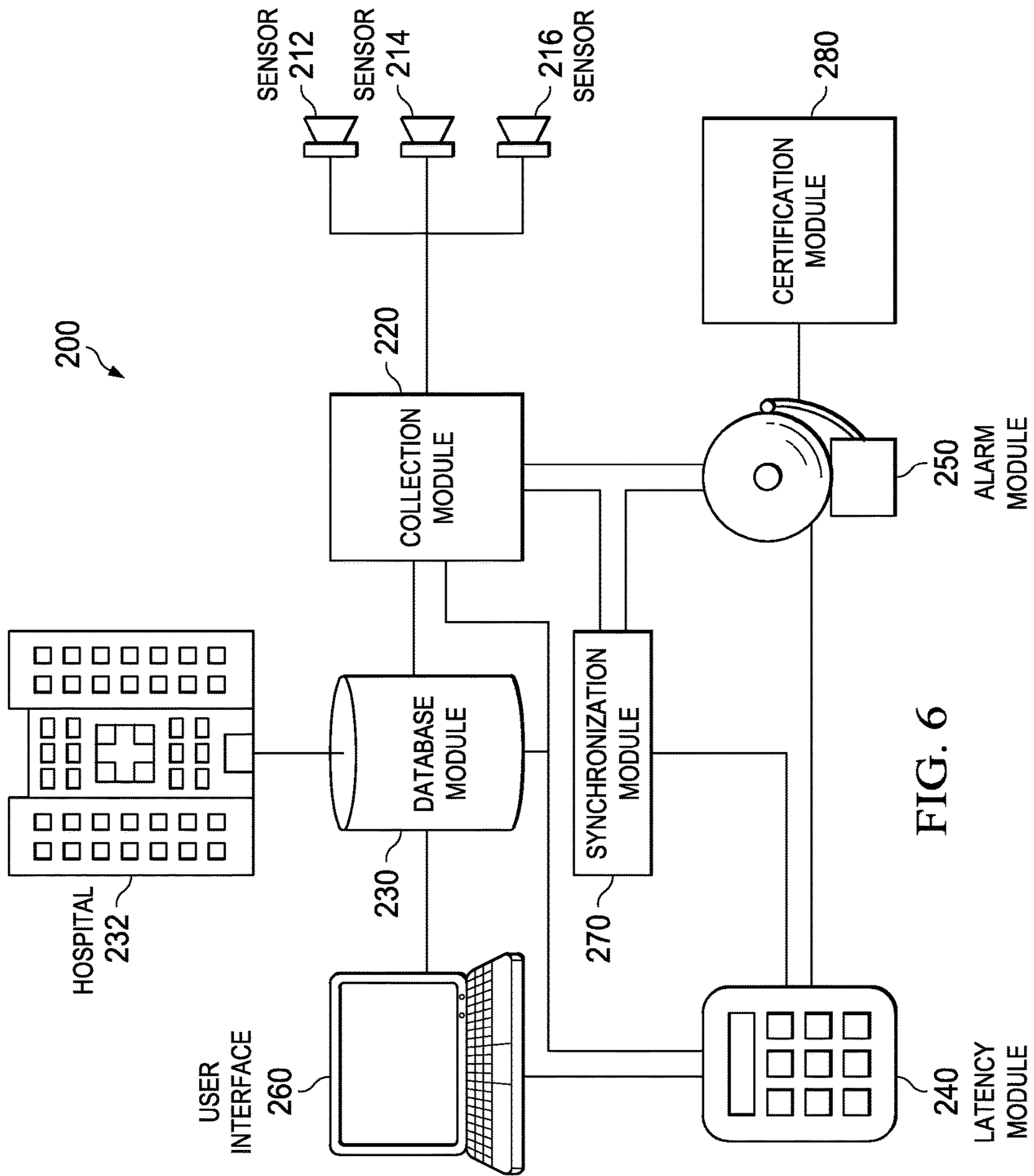


FIG. 6

300

| SENSOR | VALUE | LATENCY | ALERT | CERTIFICATION |
|--------|-------|------------|--------|---------------|
| 1 | 30 | 4 SECONDS | GREEN | GOLD |
| 2 | 4.6 | 0 SECONDS | GREEN | GOLD |
| 3 | 16 | 20 SECONDS | YELLOW | SILVER |
| 4 | 80 | 4 MINUTES | RED | NONE |

FIG. 7

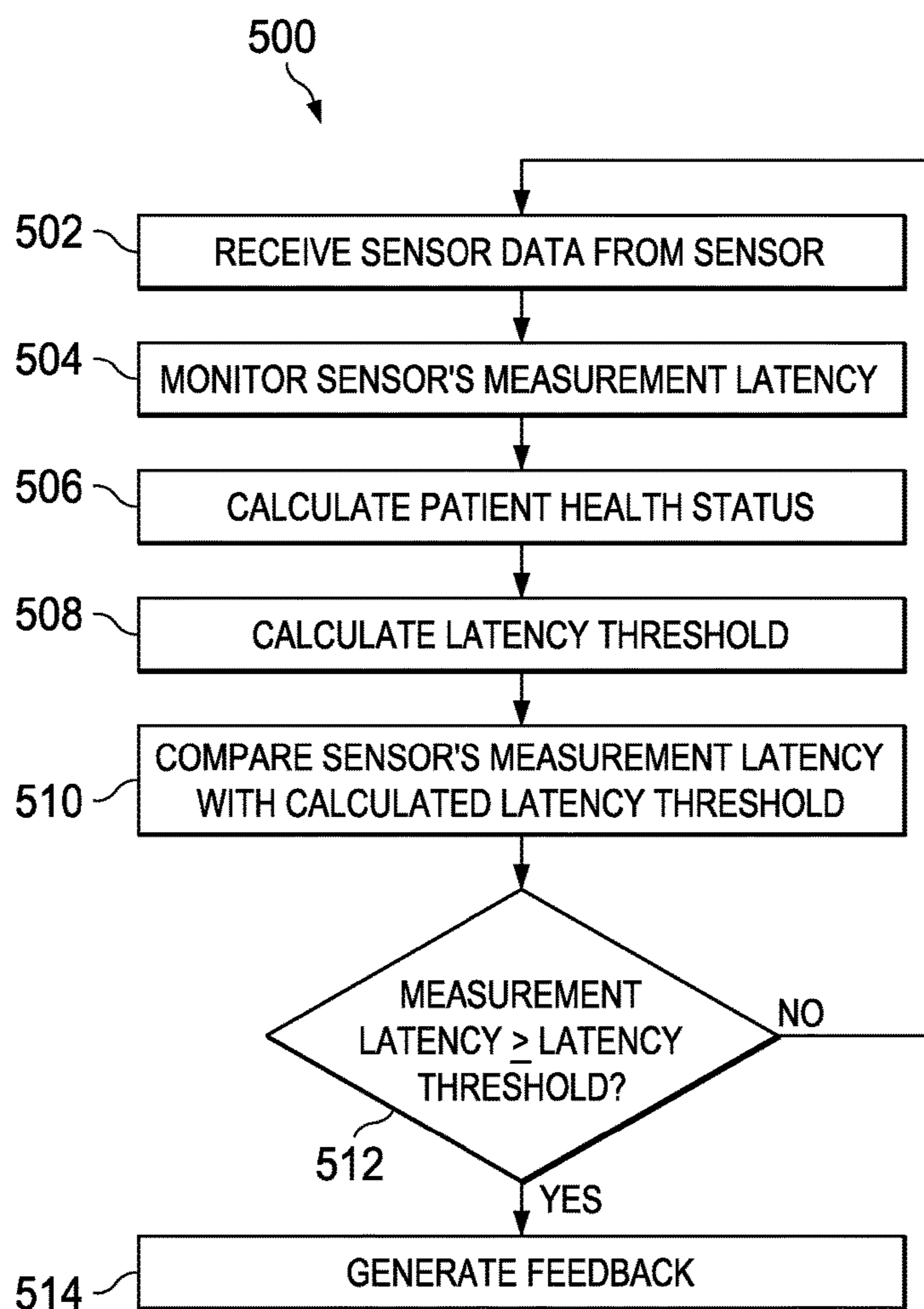


FIG. 8

**REAL-TIME MONITORING SYSTEMS AND
METHODS IN A HEALTHCARE
ENVIRONMENT**

CROSS-REFERENCE TO RELATED
APPLICATION

This application is a continuation of U.S. patent application Ser. No. 14/835,709, filed on Aug. 26, 2015 and entitled REAL-TIME MONITORING SYSTEMS AND METHODS IN A HEALTHCARE ENVIRONMENT which relates to and claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Ser. No. 62/042,110, filed on Aug. 26, 2014 and entitled REAL TIME MONITORING SYSTEMS AND METHODS, the disclosures of each of which are hereby incorporated by reference in its entirety.

TECHNICAL FIELD

This disclosure relates in general to the field of healthcare systems and, more particularly, to systems and methods related to real time monitoring in a healthcare environment.

BACKGROUND

The background description includes information that may be useful in understanding the present disclosure. It is not an admission that any of the information provided herein is prior art or relevant to the disclosure, or that any publication specifically or implicitly referenced is prior art.

Real-time monitoring of a patient or potential patient data can be crucial during times of a medical crisis. A difference of a few minutes or even seconds could mean the difference between life and death of the patient, or the difference between a brain-dead patient and a patient that is merely unconscious. As a result, a multitude of real-time monitoring sensors and systems have been developed to ensure that a patient's vitals are reported to appropriate entities in real-time.

For example, certain implantable medical devices periodically test a patient's vital stats to ensure that the current record of the patient's stats are always up to date. The medical device regularly polls the patient's stats at the same time every day. However, the system may over-test and over-report a patient's vital signs within time periods that are too short, wasting log space and possibly shortening the lifespan (i.e., loss of battery life) of the device by performing too many tests within an unnecessarily short period.

In another example, a monitoring sensor is implanted in the toilet of the patient. Whenever the patient urinates, the sensor tests the patient's urine to report the patient's vital information. Such a system, however, depends upon the patient's waste management schedule. If the patient doesn't need to eliminate waste, or uses a different toilet, extended periods of time may occur between testing cycles, making the reporting data unreliable.

In yet another example, a sensor system detects when a sensor is unable to report information, and during that interlude reports an estimated sensor value extrapolated from past sensor trend data. The estimated sensor value, however, may not be entirely accurate and violates the concept of real-time monitoring, since some vital information is not easily predicted using trends, especially during times of a medical emergency.

In yet another example, a sensor is embedded within a probe delivery device, ensuring that sensor data is created

virtually as the probes are collected from the patient's body. Not all sensors, however, can be integrated into a patient's body to ensure that data is gathered so rapidly. Some sensors will inevitably have long periods of time in between collection periods.

In yet another example, a system collects sensor data at a rapid rate, ensuring that all data is at most 10 minutes old, and at times ensuring that all data is at most 0.1 seconds old. Again, some sensors may not be able to be configured to collect data at 0.1 second intervals, and there are some vital signs that don't need to be checked so often.

In yet another example, a real-time system monitors a patient in radiation therapy. The system refreshes the data collection in real-time (e.g., a time period that is not humanly discernible). Even if data collection is humanly discernible, however, some data need not be tested so many times in a row. Some vital signs could be tested every 0.1 second, while other vital stats could be checked every day or so.

Thus, there is still a need for systems and methods that ensure real-time data collection, which medical professionals could use to dictate when data is collected rapidly enough to be considered real-time for targeted intents or purposes.

All publications identified herein are incorporated by reference to the same extent as if each individual publication or patent application were specifically and individually indicated to be incorporated by reference. Where a definition or use of a term in an incorporated reference is inconsistent or contrary to the definition of that term provided herein, the definition of that term provided herein applies and the definition of that term in the reference does not apply.

SUMMARY

An apparatus for real time monitoring of a patient is provided and includes a memory element for storing data, a processor that executes instructions associated with the data, an interface that receives sensor data from a sensor that takes measurements from the patient and sends the sensor data according to the sensor's measurement latency, a latency calculator that frequently calculates a latency threshold that varies according to at least a health status of the patient, a timer that continuously monitors the sensor's measurement latency, a comparator that frequently compares the sensor's measurement latency with the calculated latency threshold, and a feedback module that automatically changes the sensor's measurement latency to match with the calculated latency threshold. Thus, the disclosed system is able to adaptively or contextually determine the requirements or conditions for real-time monitoring of a patient or patient data.

As used herein, the term "latency" refers to a time delay determined at the apparatus between two consecutive measurements transmitted by the sensor. The sensor's measurement latency as determined at the apparatus can be influenced by (i) an inherent delay at the sensor between measuring a health parameter of the patient, processing it into transmittable sensor data, and transmitting the sensor data, and (ii) network latency inherent in a communication channel (e.g., wireless, Ethernet, optical fiber, etc.) between the apparatus and the sensor. For example, the sensor may measure a blood pressure of the patient; a digital signal processor at the sensor may convert analog readings of the blood pressure into digital data; a network interface card at the sensor may convert the digital data into network communication packets—a time delay may be inherent in these processes at the sensor. In addition, in some embodiments,

the communication packets may be transmitted by the sensor across a wireless interface to the apparatus; the wireless medium may inherently add latency to the communication.

BRIEF DESCRIPTION OF THE DRAWINGS

To provide a more complete understanding of the present disclosure and features and advantages thereof, reference is made to the following description, taken in conjunction with the accompanying figures, wherein like reference numerals represent like parts, in which:

FIG. 1 is a simplified block diagram illustrating a system for real time monitoring according to an example embodiment;

FIG. 2 is a simplified diagram illustrating example details of the system according to an embodiment;

FIG. 3 is a simplified block diagram illustrating other example details of the system according to an embodiment;

FIG. 4A is a simplified block diagram illustrating yet other example details of the system according to an embodiment;

FIG. 4B is a simplified block diagram illustrating yet other example details of the system according to an embodiment;

FIG. 4C is a simplified block diagram illustrating yet other example details of the system according to an embodiment;

FIG. 4D is a simplified block diagram illustrating yet other example details of the system according to an embodiment;

FIG. 5 is a simplified block diagram illustrating yet other example details of the system according to an embodiment;

FIG. 6 is a simplified block diagram illustrating yet other example details of the system according to an embodiment;

FIG. 7 is a simplified diagram illustrating example details of the system according to an embodiment; and

FIG. 8 is a simplified flow diagram illustrating example operations that may be associated with an embodiment of the system.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

Turning to FIG. 1, FIG. 1 is a simplified block diagram illustrating a system 10 according to an example embodiment. The disclosure herein provides apparatus, systems and methods in which a computer system is configured to examine information collected by sensors monitoring a patient and determine whether the sensor data is collected rapidly enough to be considered “real-time” information. A sensor 12 monitors a patient (not shown), and generates sensor data 14 comprising measurements of one or more health parameters of the patient. Examples of sensor 12 include global positioning system (GPS) locators, pulse and blood pressure monitors, pulse oximeters, galvanometers, blood glucose monitors, body temperature monitors, and catheter monitors. By way of examples, and not as limitations, sensor data 14 can include location information, pulse information, blood pressure information, blood chemical concentration level information, body temperature information, respiration level information, and fluid level information. Sensors 12 could be configured to be attached or implanted into the patient, or could be located within the vicinity of the patient, such as a room that the patient uses on a regular basis.

Sensor 12 transmits sensor data 14 to an adapter 16 according to a measurement latency of sensor 12; adapter 16

receives sensor data 14 over an interface 18. Sensor data 14 may be transmitted via any suitable communication medium in different embodiments, for example using wired (e.g., RS-232, Ethernet, USB, etc.) or wireless signals (e.g., WUSB, Bluetooth®, WiFi, WiGIG, WiMAX, etc.) received by a transmitter, printouts read by a scanner, tissue or bodily fluid samples tested by a lab, or information input from a nurse or doctor into the system using a computer user interface. In some embodiments, one or more interfaces are typically used as a bridge to help transmit sensor data 14 from sensor(s) 12 to one or more computer systems.

In a general sense, because information collection systems inherently have a delay, adapter 16 includes a latency calculator 20 that determines how much of a delay is acceptable to be considered information that has been collected in ‘real time.’ The threshold for this delay is referred to herein as “latency threshold” 22 possibly with respect to a targeted intent or purpose. Latency calculator 20 frequently calculates latency threshold 22 for sensor data 14. A timer 24 monitors time of receipt of sensor data 14 at adapter 16 and thereby substantially continuously monitors sensor 12’s measurement latency. In some embodiments, timer 24 monitors sensor 12’s measurement latency based in two consecutive receipts of sensor data 14, among multiple measurements (e.g., rolling average over N difference measurements, etc.), based on slopes of measurement rates, or other factors. In an example embodiment, timer 24 monitors frequency of incoming sensor data 14 (e.g., in the form of sensor pulses) from sensor 12. In a general sense, latency threshold 22 indicates a threshold or criterion, where any measurement latency at or above latency threshold 22 (or otherwise fails to satisfies the criteria), is considered unacceptable and any measurement latency below latency threshold 22 (or otherwise satisfies the criteria), is considered acceptable. Measurement latency and latency threshold 22 could be defined in units of time, such as microseconds, milliseconds, seconds, minutes, or hours. A comparator 26 frequently compares the sensor’s measurement latency with calculated latency threshold 22. Sensor data 14 that is received at adapter 16 within latency threshold 22 could be considered “real-time” information, whereas sensor data 14 that is received at adapter 16 after latency threshold 22 has lapsed could be considered “retrospective” information.

A feedback module 28 may provide feedback according to the comparison at comparator 26. For example, if sensor data 14 is retrospective information, feedback module 28 may automatically change sensor 12’s measurement latency to match with calculated latency threshold 22. In another example embodiment, if sensor data 14 is retrospective information, feedback module 28 may generate an alert at an alert user interface 30. Various other feedback actions may be facilitated according to the broad scope of the embodiments.

In various embodiments, adapter 16 may be provisioned with firmware 32 that can provide various functionalities as described herein. In one example embodiment, firmware 32 includes an application specific integrated circuit (ASIC) programmed with latency calculator 20, comparator 26, and feedback module 28 with associated memory for storing calculated latency threshold 22. A processor 34 may provide processing functionalities not included in firmware 32. A memory element 36 may comprise various memory storage functions of adapter 16. In another example embodiment, firmware 32 may comprise a volatile memory that includes instructions for executing functionalities of latency calculator 20, comparator 26, and feedback module 28 with associated memory for storing calculated latency threshold 22.

Processor **34** may execute the instructions from firmware **32** appropriately. In an example embodiment, adapter **16** may comprise or be an integral part of, the Nant Health, LLC, HBox® device. In some embodiments, adapter **16** could include one or more computer systems operating according to the Nant Health, LLC, DeviceConX™ software platform.

In various embodiments, adapter **16** may communicate with a database **38** over a network **40** through a clinical operating system (cOS™) **42**, possibly offered by Nant Health, LLC (see URL nanthealth.com/cos-clinical-operating-system). In various embodiments, cOS **42** executes on a server **44** in network **40** remote from adapter **16**. Example suitable cOS **42** that can be suitably adapted for use with the disclosed subject matter includes those described by U.S. Pat. No. 8,689,008, and U.S. pre-grant publications 2011/0313787, 2013/0054272, 2013/0144653, 2013/0166317, 2013/0304512, and 2013/0304496, the disclosures of which are incorporated herein in their entireties. Database **38** may provide various patient health status factors **46**, using which latency calculator **20** at adapter **16** can determine latency threshold **22**. In various embodiments, the patient health status comprises a data construct of an aggregate of health conditions, population characteristics, diseases, symptoms, medications and medical status of the patient, indicative of a context of measurements by sensor **12**. An administration user interface **48** may interface with adapter **16** through cOS **42** to provide various latency calculation settings **50**.

In various embodiments, patient health status factors **46** may include various parameters and corresponding values that influence latency threshold **22**. By way of examples, and not as limitations, patient health status factors **46** include patient location, patient disease or health condition (e.g., diabetes, heart disease, etc. for example, formatted as International Statistical Classification of Diseases and Related Health Problems (ICD-9 codes)), physician location, clinical pathways associated with the patient, patient's treatment regimen, genomic health indicators, demographic information and contextual information relevant to sensor data **14** (e.g., patient in emergency room following cardiac arrest; patient checking fasting blood sugar at home according to daily health regimen; patient on a regular exercise walk; patient in maternity ward about to have a C-section; etc.). Virtually any suitable parameter that affects a health status of the patient could be included in patient health status factors **46**.

In various embodiments, latency calculation settings **50** may provide variables, values, or algorithms for calculating latency threshold **22**. In one example embodiment, latency calculations settings **50** may indicate that latency threshold **22** be calculated as a function of one or more of patient health status factors **46** and a type of the sensor data **14** being collected. For example, latency threshold **22** of blood sugar measurement for a patient without diabetes may be 30 minutes, whereas latency threshold **22** of blood sugar measurement for another patient with diabetes may be 10 minutes. In another example, latency threshold **22** of blood pressure measurement for a patient at a trauma center may be 5 minutes, whereas latency threshold **22** of blood pressure measurement for a patient monitoring her general health at her home may be 1 week.

In some embodiments, latency calculation settings **50** may indicate several latency thresholds for sensor **12**, allowing for granulated feedback (e.g., alerts). For example, a heartbeat sensor could be associated with a 'yellow' latency threshold of 10 seconds, an 'orange' latency threshold of 30 seconds, and a 'red' latency threshold of 1 minute, where the color indicates a level of urgency or importance.

In some embodiments, latency calculation settings **50** may indicate contextual information (e.g., time, location, area congestion, demographic, genomic information, health trends, user preferences, etc.) for latency threshold calculations. For example, latency threshold **22** for a patient next to a sports stadium may be lower than latency threshold **22** for the patient next to a freeway entrance. In another example, latency threshold **22** for a patient in the urgent care wing of a hospital may be higher than latency threshold **22** for the patient in an outpatient area. In some embodiments, latency calculation settings **50** may indicate that latency calculator **22** take into consideration the location of the patient relative to a nearest healthcare provider. For example, latency threshold **22** for a patient located 5 minutes away from the nearest acceptable doctor may be higher than latency threshold **22** for another patient located 30 minutes away from the nearest acceptable doctor.

In some embodiments, adapter **16** may interface with more than one sensor **12**. In such embodiments, latency calculation settings **50** may indicate that latency calculator **20** take into consideration the type of sensor data **14**. For example, blood sugar measurement latency threshold may be higher than pulse measurement latency threshold. In another example, latency calculation settings **50** may indicate a dependence of latency threshold for one sensor on latency threshold for another sensor. For example, where sensor data from a first sensor affects sensor data from a second sensor, latency threshold **22** for the first sensor may be lower than latency threshold **22** for the second sensor.

In some embodiments, latency calculation settings **50** may configure latency calculator **20** to add or subtract a buffer latency to calculated latency threshold **22**. The buffer latency could be associated with the patient and be stored as part of the patient's health status in database **38** in some embodiments. In other embodiments, buffer latency could be associated with a healthcare provider or location and provided to adapter **16** as part of latency calculation settings **50**. Buffer latency may be provided in some embodiments where adapter **16** does not have sufficient processing capabilities to compute buffer latency based on network settings and other variables.

In some embodiments, a user, such as a doctor or other healthcare professional, can tweak one or more latency calculation settings **50**, including buffer latency, through administration user interface **48**. In some embodiments, administration user interface **48** may provide a selectable menu from which the user can select a set of pre-defined functions for each sensor type, and to modify such functions for a patient or type of patient. The functions, including modifications thereof, may be included in latency calculation settings **50** and can be used to configure (e.g., program, update, etc.) adapter **16**.

In some embodiments, feedback module **28** triggers an alert when measurement latency of sensor **12** as measured by frequency of incoming sensor data **14** exceeds calculated latency threshold **22**. Any suitable alert mechanism could be used, for example sending a page to a healthcare provider or displaying an indicator, such as a red light, on a user interface. Such alerts could be transmitted in audio, visual, or tactile form in locations proximal to a patient to locations very far away from the patient. In some embodiments, alert user interface **30** may be used to allow the user to configure the type of alert, although pre-defined alerts could be programmed into system **10**. For example, if the sensor's measurement latency falls above latency threshold **22**, system **10** could be configured to automatically derive the nearest healthcare provider and send an alert to that health-

care provider. Feedback module **28** could also trigger an alert when two sensors that should be reporting in-sync are out of sync with one another. For example, feedback module **28** might be programmed to ensure that the collection periods of two different sensors are within 20 seconds of one another, where a first sensor always collects information prior to a second sensor collecting information. One should appreciate that the disclosed techniques provide many advantageous technical effects including allowing a plurality of definitions for what is considered “real time,” which may be dependent upon a particular patient’s health status instead of on a global number applied universally to all patients. Thus, the definition of “real time” directly impacts the functionality of the devices disclosed herein to ensure the definition is enforced.

Turning to the infrastructure of system **10**, the network topology of network **40**, including the network connecting to adapter **16** and/or sensor **12** can include any number of servers, routers, gateways, and other nodes inter-connected to form a large and complex network. A node may be any electronic device, client, server, peer, service, application, or other object capable of sending, receiving, or forwarding information over communications channels in a network. Elements of FIG. **1** may be coupled to one another through one or more interfaces employing any suitable connection (wired or wireless), which provides a viable pathway for electronic communications. Additionally, any one or more of these elements may be combined or removed from the architecture based on particular configuration needs.

System **10** may include a configuration capable of Transmission Control Protocol/Internet Protocol (TCP/IP) communications for the electronic transmission or reception of data packets in a network. Healthcare monitoring system **10** may also operate in conjunction with a User Datagram Protocol/Internet Protocol (UDP/IP) or any other suitable protocol, where appropriate and based on particular needs. In addition, gateways, routers, switches, and any other suitable nodes (physical or virtual) may be used to facilitate electronic communication between various nodes in the network.

Note that the numerical and letter designations assigned to the elements of FIG. **1** do not connote any type of hierarchy; the designations are arbitrary and have been used for purposes of teaching only. Such designations should not be construed in any way to limit their capabilities, functionalities, or applications in the potential environments that may benefit from the features of healthcare monitoring system **10**. It should be understood that system **10** shown in FIG. **1** is simplified for ease of illustration.

The example network environment may be configured over a physical infrastructure that may include one or more networks and, further, may be configured in any form including, but not limited to, local area networks (LANs), wireless local area networks (WLANs), virtual local area networks (VLANs), metropolitan area networks (MANs), wide area networks (WANs), virtual private networks (VPNs), Intranet, Extranet, any other appropriate architecture or system, or any combination thereof that facilitates communications in a network.

In some embodiments, a communication link may represent any electronic link supporting a LAN environment such as, for example, cable, Ethernet, wireless technologies (e.g., IEEE 802.11x), ATM, fiber optics, etc. or any suitable combination thereof. In other embodiments, communication links may represent a remote connection through any appropriate medium (e.g., digital subscriber lines (DSL), telephone lines, T1 lines, T3 lines, wireless, satellite, fiber

optics, cable, Ethernet, etc. or any combination thereof) and/or through any additional networks such as a wide area networks (e.g., the Internet).

In various embodiments, adapter **16** can include computer executable instructions stored on one or more non-transitory computer-readable media (e.g. adapter firmware **32**, including hard drives, optical storage media, flash drives, ROM, RAM, etc.) that, when executed by one or more processors (e.g., processor **34**), cause the processors to execute the functions and processes described herein. In some embodiments, some functionalities of adapter **16** may be implemented in a distributed manner, for example, at server **44** (through cOS **42**). In some embodiments, adapter **16** may be generally compatible with any type of sensor, but may be specifically configured to calculate latency threshold **22** for the specific type of sensor data **14** from sensor **12** with which it interfaces. In other embodiments, adapter **16** may be configured to be compatible with only one type of sensor **12**, for example, with different adapters for different sensor types. Example devices that may be suitable for adaption according to the disclosed techniques include device server product offerings from Lantronix®, Digi®, or Moxa®. For example, the Digi One SP or the wireless (e.g., 802.11b) Digi Connect Wi-SP device servers can be configured with firmware according to the disclosed techniques.

In various embodiments, cOS **42** may include a suitable operating system (or platform, or other appropriate software) that can federate various disparate data (e.g., from health providers, patients, sensors, other medical devices, etc.), aggregate the data in disparate formats to a uniform format (e.g., JSON, YAML, XML based format), and store the uniformly formatted data in a suitable data store (e.g., federated centralized database; data store for aggregated data) such as database **38** in network **40**. cOS **42** may comprise a plurality of self-contained interconnected modules and service layers for connecting proprietary (and public) systems together and extracting and translating data therefrom to enable them to cooperate in a software ecosystem while allowing flexible connections with both existing and new applications. cOS **42** may offer a secure communication tunnel for adapter **16** to interface with database **38**, administration user interface **48** and alert user interface **30**. In some embodiments, cOS **42** can generally allow adapter **16** to interface with various other computer systems and/or adapters in network **40**.

Turning to FIG. **2**, FIG. **2** is a simplified diagram illustrating example details according to an embodiment of system **10**. A hypothetical graph **56** shows sensor data **14** plotted against time on the X-axis. Sensor **12**’s measurement latency at time i can be derived as $\text{latency}(i) = T(i) - T(i-1)$; in other words, the latency at any instant of time is the time difference (e.g., time delay) between the time at measurement i and the previous time at measurement $(i-1)$. Assume that the patient has stable health status initially. Latency threshold **22** for the initial measurements may be 10 minutes. Thus, sensor **12** may measure the patient every 10 minutes. Assume that between the measurement at 20 minutes and the next measurement at 30 minutes, the patient suffers a worsening health condition (e.g., blood sugar rises uncontrollably, blood sugar drops precariously, etc.), as indicated by sensor data **14**.

In some embodiments, sensor data **14** may be communicated to database **38**, which may process sensor data **14**, convert into one or more patient health status factors **46** and transmit to adapter **16**. In other embodiments, adapter **16** may use sensor data **14** directly to calculate latency threshold **22**. Latency calculator **20** may recalculate latency thresh-

old **22** to be 2 minutes, rather than 10 minutes, based on the changing patient's health status. Comparator **26** may compare sensor **12**'s measurement latency of 10 minutes with latency threshold **22** of 2 minutes and identify a discrepancy. Feedback module **28** may alter measurement latency of sensor **12** to match with latency threshold **22**. Sensor **12** may thereafter measure the patient every 2 minutes. Thus, it should be appreciated that latency threshold **22** adapts to the patient context or health status context.

Assume that sensor data **14** (and/or other parameters) indicates that the patient's health status improves at 40 minutes. Latency calculator **20** may recalculate latency threshold **22** to be 5 minutes, rather than 2 minutes, based on the changing patient's health status. Comparator **26** may compare sensor **12**'s measurement latency of 2 minutes with latency threshold **22** of 5 minutes and identify a discrepancy. Feedback module **28** may alter measurement latency of sensor **12** to match with latency threshold **22**. Sensor **12** may thereafter measure the patient every 5 minutes. Thus, latency threshold **22** may be calculated to be a function of the patient health status (e.g., latency threshold= $f_1(\text{patient health status})$), which in turn may be a function of sensor data (e.g., patient health status= $f_2(\text{sensor data})$; latency threshold= $f_1(f_2(\text{sensor data}))$). In various embodiments, measurement latency of sensor **12** may decrease with worsening health status, and increase with improving health status. In other words, the concept of real-time monitoring may change depending on the patient's health status.

Turning to FIG. 3, FIG. 3 is a simplified block diagram illustrating example details according to an embodiment of system **10**. Sensor data **14** may influence (e.g., affect, change, determine, etc.) patient health status factors **46**. In some embodiments, sensor data **14** may affect latency calculation settings **50**. For example, sensor data **14** of blood sugar of a patient who has hitherto not had a diagnosis of diabetes indicates onset of diabetes; thereafter latency calculation settings **50** may be changed to include a location of the nearest dialysis center. Sensor data **14** may affect patient health status factors **46**; for example, a suddenly low blood sugar reading may indicate hypoglycemia.

In some embodiments, latency threshold **22** varies according to latency sensitivity factors **58**. In an example embodiment, latency sensitivity factors **58** can include a subset of latency calculation settings **50**. For example, latency calculation settings **50** may include location of dialysis center=2 miles from patient location; location of nearest emergency center=5 miles from patient location; latency threshold for heart patient=2 seconds for blood oxygen level readings; etc. Latency sensitivity factors **58** for latency threshold **22** for a blood sugar monitor sensor **12** may derive therefrom various factors that affect blood sugar readings and/or latency thresholds thereof, while ignoring settings of factors that do not affect blood sugar readings and/or latency thresholds thereof. In another example, latency sensitivity factors **58** may include functions that affect latency threshold calculations; for example, latency sensitivity factors **58** may include a linear function of latency threshold **22** with blood sugar readings; the actual blood sugar readings may be obtained from sensor data **14**.

Patient health status factors **46** and latency sensitivity factors **58** may be input into an implementation of a latency algorithm **60** that outputs latency threshold **22**. In some embodiments, latency algorithm **60** may be pre-configured into adapter **16**. In other embodiments, latency algorithm **60** may be pre-selected by a user and used to configure latency calculator **20** in adapter **16**. Comparator **26** may compare sensor **12**'s measurement latency **62** with calculated latency

threshold **22** and generate a feedback **64** that may be used to change sensor's measurement latency **62** to match with latency threshold **22**. Some embodiments include a rules interface (e.g., GUI, user interface, API, etc.) through which a stakeholder is able to define or implement rules logic for latency algorithm **60**. For example, a stakeholder could download a script (e.g., Python, Lua, Java, C#, etc.) to adapter **16** where the script defines the operations necessary to calculate latency threshold **22** based on contextual data, internal or external, available to adapter **16**.

Turning to FIGS. 4A-4D, FIGS. 4A-4D are simplified block diagrams illustrating example details of interfaces according to embodiments of system **10**. In one example embodiment, as indicated by FIG. 4A, adapter **16** may be coupled to sensor **12** over a Universal Serial Bus (USB) interface **18**. In another example embodiment, as indicated by FIG. 4B, adapter **16** may be integrated with sensor **12** and communicate with cOS **42** over a wireless interface **18**. In another example embodiment, as indicated by FIG. 4B, adapter **16** may be integrated with a computing device or network element (e.g., switch) and communicate with sensor **12** over wireless interface **18**. In yet another example embodiment, as indicated by FIG. 4C, adapter **16** may comprise a wireless component that is connected to a computer **66** over a USB interface and communicate with sensor **12** over a wireless interface **18**. In some embodiments, computer **66** may communicate with (or be attached to) sensor **12**, and adapter **16** may communicate with sensor **12** directly through computer **66**. In yet another embodiment, as indicated by FIG. 4D, adapter **16** may include a wired (e.g., USB) interface **18** and another wireless interface **18**. Various different types of interfaces **18** may be used within the broad scope of the embodiments.

Turning to FIG. 5, FIG. 5 is a simplified block diagram illustrating example details of an embodiment of system **100**. The example hardware schematic indicates a data network **110**, a sensor **120** monitoring a patient **122**, a computer system **130**, a database **140**, an alert user interface **150**, and an administration user interface **160**. Data network **110** functionally connects various computing devices with one another such that data can flow from one device to another. Data network **110** comprises a package-switched network, a LAN, a WAN, a VPN, an intranet, an internet, or the Internet network. Data network **110** could comprise any suitable wired or wireless network known in the art using known protocols.

Sensor **120** gleans sensor data **14** from patient **122**, and transmits sensor data **14** through data network **110** to computer system **130** through a sensor interface **132**. In various embodiments, sensor interface **132** may comprise Bluetooth™ connection, WiFi connection, Ethernet connection, serial port, or other electronic data connection. Sensor **120** could comprise any suitable measuring device that monitors patient **122** and transmits sensor data **14** over data network **110** to computer system **130**. In example embodiments, sensor **120** may include GPS/WiFi/RFID locators, pulse and blood pressure monitors, blood glucose monitors, body temperature monitors, and catheter monitors. In various embodiments, sensor data **14** includes location information, pulse information, blood pressure information, blood chemical concentration level information, body temperature information, respiration level information, and fluid level information. Sensor **120** may be configured to be attached or implanted into patient **122**, or could be located within a room that patient **122** uses on a regular basis.

Sensor data **14** transmitted to computer system **130** via sensor interface **132** may be processed by computer system

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130 to determine a health status of patient 122, and to determine whether sensor data 14 is in real-time. Computer system 130 has access to database 140, which may comprise a non-transient computer-readable memory storage device that generally holds relevant information used by computer system 130, such as software to perform system functions, health data about one or more patients, including patient 122, configuration data regarding latency thresholds, locations of healthcare providers, abilities of healthcare providers, and other medically relevant data. Computer system 130 automatically calculates latency threshold 22 for sensor 120 based upon the type of sensor data 14 received and the health status of patient 122, monitors incoming sensor data 14 from sensor 120, and sends an alert to one or more alert locations if sensor's measurement latency 62 data exceeds the calculated latency threshold 22. Alert user interface 150 comprises one such alert location that computer system 130 sends a triggered alert to. While alert user interface 150 is shown as a portable user interface functionally coupled to data network 110, alert user interface 150 could be sent the alert through other communication means without departing from the scope of the disclosure.

An administration user interface 160 can configure, update, and glean information from computer system 130 through data network 110. While computer system 130 generally has a table (e.g., a look-up table) of formulas that are applied to different sensors and to patients of various health statuses, administration user interface 160 could be used to customize a calculated formula for specific patient 122, or a group of patients, and/or could be used to add or subtract a buffer latency to the calculated formula. Administration user interface 160 could also be used to update information on any health status of patient 122, or could be used to monitor the real-time status of a plurality of sensors that are collecting information from patient 122.

Turning to FIG. 6, FIG. 6 is a simplified block diagram illustrating an example real-time monitoring system 200. System 200 comprises sensors 212, 214, and 216, collection module 220, database module 230, latency module 240, alarm module 250, user interface 260, synchronization module 270, and a certification module 280. Sensors 212, 214, and 216 monitor a patient (not shown) and are configured to send respective sensor data to collection module 220 in any suitable manner. For example, sensors 212, 214, and 216 could be configured to send information to collection module 220 according to a timer, collection module 220 could be configured to instruct sensors 212, 214, and 216 to send data after a certain time period has passed, or collection module 220 could be configured to regularly send requests to sensors 212, 214, and 216 in accordance with a schedule. Collection module 220 generally sends the collected sensor data to database module 230 to update the patient's health status, to latency module 240 to help determine whether the sensor data is in real-time, and to alarm module 250 to help determine whether an alert needs to be triggered.

In some embodiments, collection module 220 could be configured to receive or retrieve sensor data from one or more sensors 212, 214, 216 via respective sensor interfaces. In some embodiments, collection module 220 could be in active mode, configured to send requests for information from sensors 212, 214, 216 at pre-defined intervals. In other embodiments, collection module 220 could be in passive mode, collecting sensor data 14 from sensors 212, 214, 216 that actively send sensor data 14 regularly at pre-defined intervals. In some embodiments, collection module 220 can

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configure sensors 212, 214, 216, for example configuring a collection time period, measurement latency, or collection sample size.

User interface 260 may be used to allow a user to administer to system 200. For example, user interface 260 could be used to review and update the health status of a patient, to review any triggered alerts, to diagnose and update the collection periods of any of sensors 212, 214, or 216, to review and update any algorithms or tables used to calculate latency threshold 22, or to define a certification schema. In some embodiments, system 200 may be configured with predefined templates to monitor sensors 212, 214 and 216 and trigger alerts without any user definitions, but could be configured to allow a user to modify or redefine algorithms and data used by system 200 without departing from the scope of the embodiments.

Database module 230 gleans, stores, and organizes information regarding the health status of the patient, such as the patient's location, designated health care providers (e.g., designated hospitals, insurance carriers, medical professionals, etc.), illnesses, medication, allergies, types of sensors monitoring the patient, sensor history, medical history, and responsible party contact information. The health status of the patient could be gleaned from a variety of sources, for example from computerized patient records, from a user interface through which a health professional inputs data, from past sensor data, or from hospital 232. In some embodiments, database module 230 may be coupled to a portion of non-transient computer readable memory (e.g., RAM, FLASH, SAN, NAS, HDD, SSD, RAID, etc.) that is dedicated towards organizing and saving patient information. The data stored by database module 230 could be gleaned from sensor data 14 collected by collection module 220.

Latency module 240 calculates latency threshold 22 for each of sensors 212, 214, and 216. In some embodiments, latency module 240 could be configured to configure a plurality of acceptable sensor measurement latencies for each sensor 212, 214, and 216, for example a first sensor measurement latency that would trigger a yellow alert warning and a second sensor measurement latency that would trigger a red alert warning. In an example embodiment, latency threshold 22 may be derived as function of at least the type of sensor data 14 and the health status of the patient. A latency table could be used by latency module 240 to determine latency threshold 22, where one axis of the table is the type of sensor data 14 and the other axis of the table is the health status of the patient. Such a latency table could be multi-dimensional to consider other factors, such as the location of the patient, the location of the patient relative to the nearest healthcare provider, or sensor data from other sensors.

In other embodiments, numerical algorithms, such as latency algorithm 60 could be used to derive the latency threshold for a particular patient. An example numerical algorithm could comprise $L=T*S-D$, where L =sensor measurement latency, T =the type of sensor, S =health status, and D =distance from nearest healthcare provider (assuming normalized units). Thus, a type of sensor having a 2 minute standard delay, monitoring the health status of a patient having a health status of severity 2 that is 30 seconds from the nearest healthcare provider could have a sensor measurement latency of $2*2-0.5=3.5$ minute sensor measurement latency. On the other hand, a type of sensor having a 1 minute standard delay monitoring the health status of a patient having a health status of severity 1 that is 45 seconds from the nearest healthcare provider could have a sensor

measurement latency of $1 \times 1 - 0.75 = 0.25$ minute, or 15 second, sensor measurement latency. Other suitable algorithms to calculate latency threshold 22 could be used without departing from the scope of the embodiments.

Alarm module 250 triggers an alarm based upon the calculated latency threshold 22 derived by latency module 240 and the actual sensor measurement latency gleaned by collection module 220. If the sensor measurement latency of any of sensors 212, 214, and 216 rises above the calculated latency threshold 22, alarm 250 triggers an alarm, which may be sent to an authorized healthcare provider. Such alarms could be sent through any suitable means, for example though an email, text message, phone call, indicator light on a remote user interface, or audio sound.

In various embodiments, synchronization module 270 may be configured such that when an alert associated with one of sensors 212, 214 and 216 is triggered by alarm module 250, synchronization module 270 automatically seeks to redefine the collection time period of sensor 212, 214 or 216 in question to prevent such alerts from occurring in the future. For example, synchronization module 270 could be configured to have collection module 220 instruct sensor 212, 214 or 216 in question to have a shorter collection time period within the bounds of calculated latency threshold 22, or synchronization module 270 could arrange to have a page sent to a technician, instructing that technician to manually redefine the time period of sensor 212, 214 or 216 in question, or perhaps replace affected sensor 212, 214 or 216. In some embodiments, for example, wherein latency threshold 22 is dependent upon another sensor (i.e. data from sensor 214 needs to be received within 1 minute of data from sensor 212) synchronization module 270 is configured to modify the collection time period of a plurality of sensors in response to a single triggered alert.

In some embodiments, synchronization module 270 may be coupled to alarm module 250 and collection module 220, such that when an alert is triggered, synchronization module 270 automatically sends a command to collection module 220 to reduce the measurement latencies (e.g., time between collection periods) to an acceptable level (e.g., matching with latency threshold 22). Where two or more sensors 212, 214 or 216 are to be synched with one another, synchronization module 270 may be configured to alter the measurement latency of one or more sensors 212, 214 or 216 as a function of the latency threshold and measurement latency of another one of sensors 212, 214 or 216. In some embodiments, synchronization module 270 can be further configured, for example in a distributed healthcare collection environment, to create a point-of-collection agent within one or more computing devices. The point-of-collection represents a node where sensor data 14 can be collected together from plurality of sensors 212, 214 and 216 in a mutually contemporaneous manner, at least to within latency threshold 22. The point-of-collection agent can bundle collected sensor data 14 as a sensor event packet and send it to an analysis module. Thus, system 10 can be assured that the sensor event packet represents a proper sensor snap shot in time.

Certification module 280 is configured to monitor alerts triggered by alert module 250, and to issue a certification when an alert is not triggered for a threshold amount of time. A plurality of different types of certifications could be handled by certification module 280. For example, a certification could be issued when a single sensor 212, 214 or 216 has not triggered an alert for a threshold period of time, a certification could be issued when all sensors 212, 214 and 216 monitoring a particular patient have not triggered an

alert for a threshold period of time, or a certification could be issued when all sensors 212, 214 or 216 monitoring all patients have not triggered an alert for a threshold period of time. A plurality of threshold periods of time could be defined for a plurality of certifications, such as a bronze certification, silver certification, or gold certification. Some certifications may allow for a few alert triggers, such as a certification that is issued when the number of alerts has stayed below a threshold number during a threshold period of time (i.e. less than 5 alerts all month long), or a certification that is issued when any alert is handled within a threshold period of time during a threshold period of time (i.e. all alerts handled under 2 hours in all year long).

In some embodiments, certification module 280 issues the certification when an alert fails to trigger within a preconfigured threshold time period. The preconfigured threshold time period may be calculated as a function of information stored in database module 230, such as past performance (e.g., most number of days without an alert) or could be defined via user interface 260. One or more threshold time periods could be defined, allowing for a plurality of certifications. For example, an area without any triggered alerts for 2 days straight could be issued a “good” certification whereas an area without any triggered alerts for 1 week straight could be issued an “excellent” certification. Other certification methods are contemplated, such as defining a certification as being dependent upon the longest time an alert has gone uncorrected within the last week, or as being dependent upon the number of repeated alerts.

Turning to FIG. 7, FIG. 7 is a simplified diagram showing a table 300 having an example user interface that shows the status of a real-time monitoring system. Table 300 shows 4 sensors, the value that is gleaned from each sensor, the latency of each sensor (i.e. time that has elapsed since the last sensor collection period), whether an alert has been triggered for each sensor, and a level of certification for each sensor.

Turning to FIG. 8, FIG. 8 is a simplified flow diagram illustrating example operations 500 that may be associated with an embodiment of system 10. At 502, adapter 16 may receive sensor data 14 from sensor 12. At 504, timer 24 may monitor sensor’s measurement latency 62. At 506, latency calculator 20 may calculate the patient’s health status, for example, based on patient health status factors 46. At 508, latency calculator 20 may calculate latency threshold 22. At 510, comparator 26 may compare sensor’s measurement latency 62 with calculated latency threshold 22. At 512, a determination may be made whether sensor’s measurement latency 62 is greater than or equal to latency threshold 22. If sensor’s measurement latency 62 is less than latency threshold 22, the operations may revert to 502. On the other hand, if sensor’s measurement latency 62 is greater than or equal to latency threshold 22, at 514, feedback 64 may be generated. In some embodiments, feedback 64 may comprise an alert. In other embodiments, feedback 64 may comprise an instruction to sensor 12 to change its measurement latency. Various other feedback actions are also possible within the broad scope of the embodiments.

It should be apparent to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts disclosed herein. Moreover, in interpreting both the specification and the claims, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms “comprises” and “comprising” should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced

elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced. Where the specification claims refers to at least one of something selected from the group consisting of A, B, C . . . and N, the text should be interpreted as requiring only one element from the group, not A plus N, or B plus N, etc.

The foregoing discussion provides many example embodiments of systems and methods for alarm fatigue management. Although each embodiment represents a single combination of various elements, all possible combinations of the disclosed elements are intended to be included in the broad scope of the disclosure. Thus if one embodiment comprises elements A, B, and C, and a second embodiment comprises elements B and D, then the scope of the disclosure is considered to include other remaining combinations of A, B, C, or D, even if not explicitly disclosed.

As used in the description herein and throughout the claims that follow, the meaning of “a,” “an,” and “the” includes plural reference unless the context clearly dictates otherwise. Also, as used in the description herein, the meaning of “in” includes “in” and “on” unless the context clearly dictates otherwise.

Unless the context dictates the contrary, all ranges set forth herein should be interpreted as being inclusive of their endpoints and open-ended ranges should be interpreted to include only commercially practical values. Similarly, all lists of values should be considered as inclusive of intermediate values unless the context indicates the contrary. Note that any recitation of ranges of values herein is merely intended to serve as a shorthand method of referring individually to each separate value falling within the range. Unless otherwise indicated herein, each individual value is incorporated into the specification as if it were individually recited herein.

Groupings of alternative elements or embodiments of the invention disclosed herein are not to be construed as limitations. Each group member can be referred to and claimed individually or in any combination with other members of the group or other elements found herein. One or more members of a group can be included in, or deleted from, a group for reasons of convenience and/or patentability. When any such inclusion or deletion occurs, the specification is herein deemed to contain the group as modified thus fulfilling the written description of all Markush groups used in the appended claims.

Note that in this Specification, references to various features (e.g., elements, structures, modules, components, steps, operations, characteristics, etc.) included in “one embodiment,” “example embodiment,” “an embodiment,” “another embodiment,” “some embodiments,” “various embodiments,” “other embodiments,” “alternative embodiment,” and the like are intended to mean that any such features are included in one or more embodiments of the present disclosure, but may or may not necessarily be combined in the same embodiments. The use of any and all examples, or exemplary language (e.g. “such as”) provided with respect to certain embodiments herein is intended merely to better illuminate the invention and does not pose a limitation on the scope of the embodiments otherwise claimed. No language in the specification should be construed as indicating any non-claimed essential.

In example implementations, at least some portions of the activities outlined herein may be implemented in software in, for example, alarm management engine 12. In some embodiments, one or more of these features may be implemented in hardware, provided external to these elements, or

consolidated in any appropriate manner to achieve the intended functionality. The various network elements may include software (or reciprocating software) that can coordinate in order to achieve the operations as outlined herein.

In still other embodiments, these elements may include any suitable algorithms, hardware, software, components, modules, interfaces, or objects that facilitate the operations thereof.

Furthermore, adapter 16 and various other components described and shown herein (and/or its associated structures) may also include suitable interfaces for receiving, transmitting, and/or otherwise communicating data or information in a network environment. Additionally, some of the processors and memory elements associated with the various nodes may be removed, or otherwise consolidated such that a single processor and a single memory element are responsible for certain activities. In a general sense, the arrangements depicted in the FIGURES may be more logical in their representations, whereas a physical architecture may include various permutations, combinations, and/or hybrids of these elements. It is imperative to note that countless possible design configurations can be used to achieve the operational objectives outlined here. Accordingly, the associated infrastructure has a myriad of substitute arrangements, design choices, device possibilities, hardware configurations, software implementations, equipment options, etc. Moreover, all methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

As used herein, and unless the context dictates otherwise, the term “coupled to” is intended to include both direct coupling (in which two elements that are coupled to each other contact each other) and indirect coupling (in which at least one additional element is located between the two elements). Therefore, the terms “coupled to” and “coupled with” are used synonymously.

In some of example embodiments, one or more memory elements (e.g., memory element 36, database 38) can store data used for the operations described herein. This includes the memory element being able to store instructions (e.g., software, logic, code, etc.) in non-transitory media such that the instructions are executed to carry out the activities described in this Specification. These devices may further keep information in any suitable type of non-transitory storage medium (e.g., random access memory (RAM), read only memory (ROM), field programmable gate array (FPGA), erasable programmable read only memory (EPROM), EEPROM, etc., software, hardware, or in any other suitable component, device, element, or object where appropriate and based on particular needs.

A processor can execute any type of instructions associated with the data to achieve the operations detailed herein in this Specification. In one example, processors (e.g., processor 34) could transform an element or an article (e.g., data) from one state or thing to another state or thing. In another example, the activities outlined herein may be implemented with fixed logic or programmable logic (e.g., software/computer instructions executed by a processor) and the elements identified herein could be some type of a programmable processor, programmable digital logic (e.g., a field programmable gate array (FPGA), an erasable programmable read only memory (EPROM), an electrically erasable programmable read only memory (EEPROM)), an ASIC that includes digital logic, software, code, electronic instructions, flash memory, optical disks, CD-ROMs, DVD-ROMs, magnetic or optical cards, other types of machine-

readable mediums suitable for storing electronic instructions, or any suitable combination thereof.

The information being tracked, sent, received, or stored in system **10** could be provided in any database, register, table, cache, queue, control list, or storage structure, based on particular needs and implementations, all of which could be referenced in any suitable timeframe. Any of the memory items discussed herein should be construed as being encompassed within the broad term ‘memory element.’ Similarly, any of the potential processing elements, modules, and machines described in this Specification should be construed as being encompassed within the broad term ‘processor.’

It is also important to note that the operations and steps described with reference to the preceding FIGURES illustrate only some of the possible scenarios that may be executed by, or within, the system. Some of these operations may be deleted or removed where appropriate, or these steps may be modified or changed considerably without departing from the scope of the discussed concepts. In addition, the timing of these operations may be altered considerably and still achieve the results taught in this disclosure. The preceding operational flows have been offered for purposes of example and discussion. Substantial flexibility is provided by the system in that any suitable arrangements, chronologies, configurations, and timing mechanisms may be provided without departing from the teachings of the discussed concepts.

Note also that the disclosed subject matter herein enables construction or configuration of an adapter to operate on digital data (e.g., raw sensor data, alarm condition, etc.), beyond the capabilities of a human or un-configured (e.g., off-the-shelf) medical device. Although the digital data represents sensor data, it should be appreciated that the digital data is a representation of one or more digital models of a patient’s medical measurements (and other indicators) and not the measurements (or indicators) themselves, which comprise activities or operations performed by sensors and/or adapters. By instantiation of such digital models in the memory of the adapter, the adapter is able to manage the digital models in a manner that could provide utility to an individual (e.g., a user of the system) that the individual would lack without such a tool.

It should also be noted that any language directed to a computer should be read to include any suitable combination of computing devices, including servers, interfaces, systems, databases, agents, peers, engines, controllers, or other types of computing devices operating individually or collectively. One should appreciate the computing devices comprise a processor configured to execute software instructions stored on a tangible, non-transitory computer readable storage medium (e.g., hard drive, solid state drive, random access memory (RAM), flash memory, read-only memory (ROM), etc.). The software instructions can configure a suitable computing device to provide the roles, responsibilities, or other functionality as discussed herein with respect to the disclosed apparatus. In some embodiments, the various servers, systems, databases, or interfaces exchange data using standardized protocols or algorithms, possibly based on hyper-text transfer protocol (HTTP), hyper-text transfer protocol secure (HTTPS), Advanced Encryption Standard (AES), public-private key exchanges, web service application programming interfaces (APIs), known financial transaction protocols, or other electronic information exchanging methods. Data exchanges preferably are conducted over a packet-switched network, the Internet, local area network (LAN), wide area network (WAN), virtual private network (VPN), or other type of packet switched network.

As used in the description herein and throughout the claims that follow, when a system, engine, server, device, module, or other computing element is described as configured to perform or execute functions on data in a memory, the meaning of “configured to” or “programmed to” refers to one or more processors or cores of the computing element being programmed by a set of software instructions stored in the memory of the computing element to execute the set of functions on target data or data objects stored in the memory.

One should appreciate that the disclosed techniques provide many advantageous technical effects including reduction in latency between a computing device ingesting health-care data and generating a prediction or recommendation. Latency is reduced through storage of health care data in a memory and in the form of N-grams, which can be computationally analyzed quickly.

Although the present disclosure has been described in detail with reference to particular arrangements and configurations, these example configurations and arrangements may be changed significantly without departing from the scope of the present disclosure. For example, although the present disclosure has been described with reference to particular communication exchanges involving certain network access and protocols, system **10** may be applicable to other exchanges or routing protocols. Moreover, although system **10** has been illustrated with reference to particular elements and operations that facilitate the communication process, these elements, and operations may be replaced by any suitable architecture or process that achieves the intended functionality of system **10**.

Numerous other changes, substitutions, variations, alterations, and modifications may be ascertained to one skilled in the art and it is intended that the present disclosure encompass all such changes, substitutions, variations, alterations, and modifications as falling within the scope of the appended claims. In order to assist the United States Patent and Trademark Office (USPTO) and, additionally, any readers of any patent issued on this application in interpreting the claims appended hereto, Applicant wishes to note that the Applicant: (a) does not intend any of the appended claims to invoke paragraph six (6) or (f) of 35 U.S.C. section 112 as it exists on the date of the filing hereof unless the words “means for” or “step for” are specifically used in the particular claims; and (b) does not intend, by any statement in the specification, to limit this disclosure in any way that is not otherwise reflected in the appended claims.

What is claimed is:

1. An apparatus for real-time monitoring of a patient, comprising:
 - an interface that receives sensor data from a sensor;
 - a memory element that stores instructions; and
 - a processor that executes the instructions to perform operations comprising:
 - determining a delay criterion that varies according to at least a health status of the patient and latency sensitivity factors;
 - continuously monitoring a time delay between measurements of the sensor;
 - comparing the time delay with the determined delay criterion; and
 - generating an alert if the time delay fails to satisfy the determined delay criterion.
2. The apparatus of claim **1**, wherein the health status of the patient is determined from at least the sensor data.
3. The apparatus of claim **1**, wherein the time delay is based on two consecutive receipts of the sensor data.

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4. The apparatus of claim 1, wherein the apparatus comprises an adapter removably attached to the sensor.

5. The apparatus of claim 1, wherein the apparatus comprises an adapter integrated with the sensor.

6. The apparatus of claim 1, wherein the apparatus comprises an adapter that communicates wirelessly with the sensor.

7. The apparatus of claim 1, further comprising a network interface that receives various delay criterion settings and patient health status factors from a remote database in a network.

8. The apparatus of claim 7, wherein the apparatus communicates with the database through a clinical operating system executing remotely in the network.

9. The apparatus of claim 1, wherein an administration user interface facilitates configuring the apparatus with algorithms to determine the delay criterion.

10. The apparatus of claim 1, wherein the patient health status comprises a data construct of an aggregate of health conditions, population characteristics, diseases, symptoms, medications and medical status of the patient, indicative of a context of measurements by the sensor.

11. The apparatus of claim 1, wherein the latency sensitivity factors include a function of the sensor data that affects the determination of the delay criterion.

12. A real-time monitoring system, comprising:

a first sensor interface that receives sensor data about a patient; and

a computer system having a processor that executes software stored on a non-transitory computer-readable memory to perform operations comprising:

retrieving sensor data from a plurality of system sensors,

storing a health status and a location of the patient,

determining a delay criterion for at least one of the system sensors as a function of at least the health status and the location of the patient, a type of sensor information from the at least one of the system sensors, and sensor data from at least one other system sensor, and

triggering an alert when a sensor's measurement delay fails to satisfy the determined delay criterion.

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13. The real-time monitoring system of claim 12, wherein the delay criterion is determined as a function of the location of the patient relative to a healthcare provider.

14. The real-time monitoring system of claim 12, wherein the operations further comprising storing a buffer delay for the patient, and the delay criterion is further determined as a function of the buffer delay.

15. The real-time monitoring system of claim 12, further comprising a user interface that allows a user to select the function used to determine the delay criterion from a set of pre-defined functions.

16. The real-time monitoring system of claim 15 wherein said user interface provides a selectable menu for a user to select a function from a set of pre-defined functions for each sensor type and modify the selected function based upon patient information.

17. The real-time monitoring system of claim 12, further comprising at least a third sensor that monitors the patient, and wherein the delay criterion is determined as a function of sensor data received from the third sensor.

18. The real-time monitoring system of claim 12, wherein the delay criterion is determined as a function of a measurement delay of the at least one other system sensor.

19. A method for real-time monitoring of a patient, the method comprising:

determining a delay criterion that varies according to at least a health status of the patient and latency sensitivity factors;

continuously monitoring a time delay between measurements of a sensor;

comparing the time delay with the determined delay criterion; and

generating an alert if the time delay fails to satisfy the determined delay criterion.

20. The method of claim 19, further comprising:

continuously monitoring a time delay between measurements of another sensor;

wherein the delay criterion varies according to the time delay between measurements of the another sensor.

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